S72-238 WCDMA systems

Tutorial 3 1.02.2002.

Solutions

1.

DS-CDMA system has spreading code rate 3.84 $\frac{Mchip}{s}$. User data rate is 15 $\frac{kbit}{s}$. How many users can one cell serve when the required level of performance requires $SIR \quad 9 \quad dB$.

1.

The capacity in CDMA system is interference limited. The interference per bit is described as energy per bit divided by total interference in the transmission bandwidth. In CDMA the interference in communication bandwidth is generated by all other users. We assume that the interference is characterised as a zero-mean AWGN process.
In CDMA the total interference power presented to each user's demodulator is,

$$I = (k_u - 1) P_n \qquad (1)$$

i.e. number of other users $(k_u - 1)$ multiplied by the signal power to one of the users. We assume here that the received signal power P_n at BS is same for all the users.

The noise density received by each user demodulator is $I_0 = \frac{I}{W}$.

The energy per bit is $E_b = \frac{P_n}{R}$.

By inserting these into (1) we get,

$$k_u - 1 = \frac{I}{P_n} = \frac{W/R}{E_b/I_0} \qquad (2)$$

This equation contains only the interference from the host cell. The interference from the other cells is f times the interference from the host cell. That means the total interference is increased by the factor $(1+f)$. Inserting this into (2) one get,

$$k_u - 1 = \frac{I}{P_n} = \frac{W}{R}\frac{I_0}{E_b}\frac{1}{(1+f)} = \frac{W}{R}\frac{1}{SIR}\frac{1}{(1+f)}, \qquad (4)$$

where $\frac{E_b}{I_0} = SIR$.

In what follows we assume that the main source of the noise is multiple access (other users) interference. This assumption allows us to set $SNR = SIR$.
In the exercise is given the target BER but in our calculations we need the SIR (or because of our assumption SNR) value. This relationship depends on particular coding and channel. Usually the required relationship is evaluated by simulations.

Coding gain is $\frac{3840000}{15000} = 256$. Inserting this values into (3) results $k_u = 256\frac{1}{10^{9/10}} + 1 \simeq 33$.

2.

The spread symbol rate is $3.84\ \frac{Mchip}{s}$. The user data rate 15 $\frac{kbit}{s}$ is spread by error correction code to 30 $\frac{kbit}{s}$. For final spreading is used Walsh code. Each user should have a unique Walsh code. How many users can be admitted into the system when:

a) The target SIR is 10 dB and other-cell relative interference factor is 0.6.
b) The target SIR is 5 dB and other-cell relative interference factor is 0.6.
c) The target SIR is 5 dB and other-cell relative interference factor is 0.2.

2.

The system is limited either by amount of available Walsh codes or interference. If the capacity limited by interference is more than amount of the available codes the system is limited by the amount of Walsh codes:

$$\frac{3.84\times10^6}{30000}=128$$

That is, we have available 128 different Walsh codes.

The number of users in the cell k_u is approximated by

$$k_u-1=\frac{I}{P_s}=\frac{W}{R}\frac{I_0}{E_b}\frac{1}{(1+f)}$$

where,
P_n received signal power,
W spread bandwidth,
R transmitted data rate,
E_b transmitted energy per signal bit,
I_0 total interference density,
f neighboring cell interference factor.

Where $\frac{E_b}{I_0}$ is carrier to interference factor that is related to the signal to interference factor by the coding gain $G=\frac{W}{R}$. The coding plus spreading gain in our system is

SIR $[dB]$	CIR	f	k_u
10	0.0195	0.6	32
5	0.0062	0.6	101
5	0.0062	0.2	134

From the table we see that only in the last case when the target SIR is 5 dB and adjacent cell interference factor is $f=0.2$, Interference allows to admit into the system more users than there are available Walsh codes.

3.

Investigate the SIR of WCDMA uplink with two users in the system. The users are at distances $d = [20 \;\; 55] \;\; m$ Attenuation in the channel is approximated as d^{-atten} where $atten = 4$.

a) Calculate the SIR for both users when no power control is applied and transmitted powers are $P_{tr} = [0.1 \; 0.1] \; W$

b) What are the transmitted powers when to assume an optimal power control and the SIR target for both users are $10 \; dB$. (The transmitted powers should be in the intervals $-50 < P < 20 \;\; dBm$)

Assume that the other user interference is scaled by the spreading gain. The chip rate is 3.84 $\frac{Mchip}{s}$ and bitrate for both users is the same 15 $\frac{kbit}{s}$.

3.

a)

Since we do not have any power control the exercise illustrates the near-far problem in CDMA system.

In CDMA the SIR is function of spreading gain $\frac{W}{R}$ and received power and interfering power ratio at receiver. The received power P_r is related to the transmitted power P_{tr} by the propagation loss (in our exercise it is d^{-4}): $P_r = P_{tr} d_1^{-4}$.

The signal to interference ratio for the first user can be expressed as:

$$SIR_1 = \frac{W}{R_1} \frac{P_{r1}}{P_{r2} + N} = \frac{W}{R_1} \frac{P_{tr1} d_1^{-4}}{P_{tr2} d_2^{-4} + N}$$

W spread signal bandwidth,

R_1 transmitted data rate,

P_{r1}, P_{r2} received powers for the first and second users accordingly,

P_{tr1}, P_{tr2} transmitted powers for the first and second users accordingly, N noise power in the received spectrum.

Noise is calculated as total thermal noise in transmission bandwidth $N = kTW$

k is Boltzman constant 1.37×10^{-23},

T temperature in Kelvins $290 \; K$.

$$N = 1.37 \times 10^{-23} \times 290 \times 3.84 \times 10^{6} = 1.53 \times 10^{-14}$$

By inserting into the equation for first user we get the following equation

$$SIR_1 = \frac{3.84 \times 10^6}{15 \times 10^3} \frac{0.1 \times 20^{-4}}{0.1 \times 55^{-4} + N} = 1.46 \times 10^4 \Rightarrow 41.7 \;\; dB,$$

and for the second user,

$$SIR_2 = \frac{3.84 \times 10^6}{15 \times 10^3} \frac{0.1 \times 55^{-4}}{0.1 \times 20^{-4} + N} = 4.47 \Rightarrow 6.5 \;\; dB.$$

When to compare these SIR levels to the target SIR_t

$SIR_1 - SIR_t = 41.7 - 10 = 31.7$, $SIR_2 - SIR_t = 6.5 - 10 = -3.5$. We see that only the first user has the satisfying channel quality.

b)
When the power control is applied the system attempts to change the power level to match the target SIR value. However, since we can not transmit at very small and very high power levels the power is limited from below and above. For example in UMTS the transmitted power in uplink should be between -50 ... 20 dB.

By transmitting its own signal users generate interference to each other. In order to find the transmitted power with power control we have to solve a system of equations containing both user powers.

From the equation for SIR we can express the transmitted power for both users:

$$P_{tr1} = \frac{R_1}{W}\frac{SIR_{t1} \times \left(P_{tr2} d_2^{-4} + N_0\right)}{d_1^{-4}},$$

$$P_{tr2} = \frac{R_2}{W}\frac{SIR_{t2} \times \left(P_{tr1} d_1^{-4} + N_0\right)}{d_2^{-4}},$$

constrained by $-50\ dBm < P_{tr1}, P_{tr2} < 20\ dBm$.
The constraints are due to the limits for possible signal powers.

By solving these equations for our parameters we get:
$P_{tr1} = -50\ dBm$,
$P_{tr2} = -46\ dBm$.
And
$CIR_1 = 38.6\ dB$,
$CIR_2 = 10\ dB$.

4.

In CDMA system are two users connected to different Base Stations. The distance matrix between the users and BS is:

$$\begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix} = \begin{bmatrix} 20 & 40 \\ 60 & 55 \end{bmatrix}$$

Attenuation in the channel is approximated as d^{-4}.
a) Calculate SIR for both users when no power control is applied and transmission powers for users are $P = [0.1\ 0.1]\ mW$.
b) What is the transmission power for both of users when to assume an optimal power control and the SIR target for both users is 10 dB.
Investigate the signals in uplink by assuming that the other users interference is scaled by the spreading gain, the chip rate is 3.84 $\frac{Mchip}{s}$, and bitrate for both users is same 15.

4.

a) This exercise is similar to the previous one with the difference that now we have to consider two BS.

The interference is other user power received by BS which is decoding the users signal. The SIR is function of spreading gain $\frac{W}{R}$ and received power and interfering power ratio at receiver. The received power P_r is related to the transmitted power P_{tr} by the propagation loss (in our exercise it is d_{11}^{-4}): $P_{r11} = P_{tr1} \times d_{11}^{-4}$.

The signal to interference ratio for the first user can be expressed as:

$$SIR_1 = \frac{W}{R_1} \frac{P_{r11}}{P_{r21} + N} = \frac{W}{R_1} \frac{P_{tr1} d_{11}^{-4}}{P_{tr2} d_{21}^{-4} + N},$$

W spread signal bandwidth,
R_1 transmitted data rate,
P_{r11}, P_{r21} received powers at BS 1 for the first and second users accordingly,
P_{tr1}, P_{tr2} transmitted powers for the first and second users accordingly,
N noise power.

Noise is calculated as total thermal noise in transmission bandwidth $N = kTW$
k is Boltzman constant 1.37×10^{-23},
T temperature in Kelvin $290\ K$.

$$N = 1.37 \times 10^{-23} \times 290 \times 3.84 \times 10^{6} = 1.53 \times 10^{-14}$$

Similar equation should be written for the users 2. Its signal is received by the BS 2.
By inserting the given values into the equation for first user we get

$$SIR_1 = \frac{3.84 \times 10^6}{15 \times 10^3} \frac{0.1 \times 20^{-4}}{0.1 \times 60^{-4} + N} = 2.1 \times 10^4 \Rightarrow 43.17\ \ dB,$$ and for the second user

$$SIR_2 = \frac{3.84 \times 10^6}{15 \times 10^3} \frac{0.1 \times 55^{-4}}{0.1 \times 40^{-4} + N} = 71.6 \Rightarrow 18.55\ \ dB.$$

b) When the power control is applied the system attempts to change the power level to match the target SIR value. However, since we can not transmit at very small and very high power levels the power is limited from below and above. For example in UMTS the transmitted power in uplink should be between -50 ... 20 dBm.

By transmitting its own signals users generate interference to each other.
In order to find the transmitted power with power control we have to solve a system of equations containing both users powers.

From the SIR equation we can express the transmitted power for both users to be:

$$P_{tr1} = \frac{R_1}{W} \frac{SIR_{t1} \times \left(P_{tr2} d_{21}^{-4} + N\right)}{d_{11}^{-4}},$$

$$P_{tr2} = \frac{R_2}{W} \frac{SIR_{t2} \times \left(P_{tr1} d_{12}^{-4} + N\right)}{d_{22}^{-4}},$$

constrained by $-50\ dBm < P_{tr1}, P_{tr2} < 20\ dBm$.
The constraints are due to the limits for possible signal powers.
By solving these equations for our parameters we get:

$P_{tr1} = -50\ dBm$,
$P_{tr2} = -50\ dBm$.
And
$CIR_1 = -43.08\ dB$,
$CIR_2 = -18.53\ dB$.

5.

How many orthogonal codes are available for the voice users with coded data rate 30 $\frac{kbit}{s}$ in CDMA uplink, if there are allocated codes for 6 data users with user data rates [130 130 130 260 260 260]. The spread chip rate is 3.84 $\frac{Mchip}{s}$.

5.

As we know in CDMA uplink each user has its own orthogonal Walsh code. The codes are selected from the channelisation code tree. For the 3.84 and 30 $\frac{kbit}{s}$ data users there are total 128 $\left(2^7\right)$ different code words. The code tree is 7 levels deep. Data users have smaller spreading factors and they are occupying the spreading codes in higher level in the code tree. After occupying a higher level spreading code, non-of the lower level code can be used. In our exercise we have to find out how many codes at the level 7 are available when at higher level are allocated the codes for given data users.

Existing data users are mapped into the channel bit rate [240 240 240 480 480 480] (see the table 6.2 in the book). The spreading factors for those code rates are $\frac{3.84\times10^6}{240\times10^3} = 16\ \left(2^4\right)$ and $\frac{3.84\times10^6}{480\times10^3} = 8\ \left(2^3\right)$.

The levels in the code tree are 3 and 4 accordingly. After allocating the codes for the 3 users at the level 3 there are still left $2^3 - 3$ spreading codes. These codes allow us to have $\left(2^3 - 3\right)\times 2$ different code at level 4. We have 3 users that are using spreading factors at length 2^4 (level 4). After allocating spreading codes for them we have left with $\left(\left(2^3 - 3\right)\times 2\right) - 3$ codes with length 4. For each of these codes we can generate 2^{7-4} different code with length 128. Therefore we have $\left(\left(\left(2^3 - 3\right)\times 2\right) - 3\right)\times 2^{(7-4)} = 56$ different code with length 128. For voice users are available 56 different orthogonal spreading codes.